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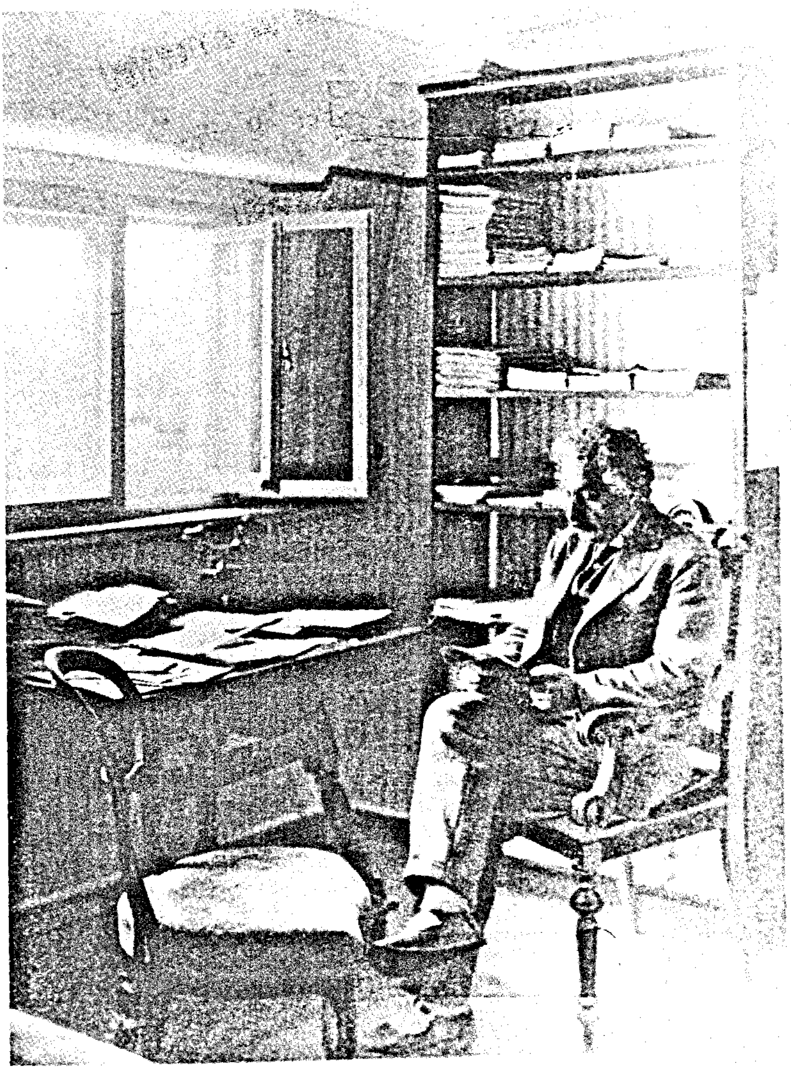

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Einstein's Interpretations of the Quantum Theory

The Argument

This paper argues that Einstein subscribed to three distinct kinds of interpretations of the quantum theory: subjective, instrumental, and hidden variables interpretations. We explore the context and the content of Einstein's thinking over these interpretations, emphasizing Einstein's conception of his role not only as a critic of the new quantum theory but also as a guide pointing the way to better physics.

...and fashion makes people deaf — at least for a while.
Albert Einstein

1. Introduction

Schrödinger introduced the quantum state function into physics in 1926. He originally tried to interpret the function as referring to a sort of fuzzy reality. For example, he tried to picture an electron — represented by a certain state function — as a pulsating bit of electricity, something like an electrical cloud or a patch of electrical fog. In short order, however, Schrödinger recognized difficulties with this interpretation; and after trying out more sophisticated refinements he abandoned the whole project. Quickly thereafter the physics community settled on the statistical interpretation of the state function given by Born's rule — roughly, that the square of the norm represents the probability density for finding measured values. Einstein too found the interpretation of the state function a challenge.

This essay examines Einstein's response to that interpretive challenge by setting it in the context of his overall critical reaction to the quantum theory. As I have

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discussed elsewhere, the apparent breakdown of realism and determinism in the quantum theory led Einstein to question the adequacy of the conceptual framework of the theory, which he felt put physics on the wrong track.[1] He believed that the basic concepts of the quantum theory involved subjective elements that compromised the ideal of observer independence, an ideal central to his realist program for physics. Einstein was equally disturbed by the statistical descriptions required by the quantum theory, which he saw as abandoning the scientific ideal of causality (or determinism). He referred bitingly to this aspect of the theory as "die flucht in die Statistik" (the flight into statistics), "eine Ausflucht" (an evasion) that he saw as "eine Sackgasse" (a dead end) for physics (from letter to B. Dessau, 2 August 1949).[2] Einstein used the challenge posed by the interpretation of the state function to criticize the theory on these two grounds and to call for something better. I argue that this fact about the critical and hortatory context of Einstein's interest in pursuing interpretive issues needs to be taken into account if we are to understand what his own interpretations might have been, and what they were not.

In correspondence with Werner Heisenberg early in 1926, Einstein criticized the new Heisenberg-Born-Jordon matrix mechanics. In his response to the criticisms, Heisenberg remarked, "Then it seems most likely to me that quantum mechanics can never make direct statements about the individual process, rather it always gives only average values in the sense of Bohr-Kramers-Slater" (letter to Einstein, 18 February 1926). It is well known that Einstein reached a similar conclusion in his own thinking about the quantum theory. He expressed it negatively in his frequent references to the theory as providing only an incomplete (or partial) description of individual systems. He put it positively when he characterized the theory as describing ensembles of systems. Einstein's emphasis on ensembles and descriptive incompleteness occurred during the informal discussions at the 1927 Solvay conference, in which Einstein made his earliest public remarks on the quantum theory. There he contrasted a "complete" with an "incomplete" interpretation of the state function and argued that difficulties with treating the state function as providing a complete description require that we adopt the ensemble view and treat it, instead, as providing an incomplete one. Exactly this same format — that is, contrasting a complete with an incomplete interpretation of the state function — is a key feature in many of Einstein's later writings. In the Solvay conference of 1927 the difficulty for the complete interpretation centered on considerations of locality in connection with the reduction of the wave packet and on the quantum approximation to the behavior of macroscopic objects. These remained Einstein's dominant concerns, although after 1935 — and the Einstein-Podolsky-Rosen (EPR) paper (Einstein et al. 1935) — he generally used coupled systems to approach the locality and reduction issues.

[1] The conclusions stated in the first two sections below concerning Einstein's views on the quantum theory are documented in Fine 1988, chaps. 1–6.

[2] All the letters cited in this paper are to be found in The Albert Einstein Archives at the Hebrew University of Jerusalem — unless otherwise indicated.

Einstein expressed his attitude toward the quantum theory repeatedly in publications and correspondence from 1926 on. In many respects the elements of his view are reasonably constant and clear. These include the following:

(A) *Measurability and the uncertainty formulas.* The uncertainty formulas, understood as posing a limitation on the measurability of certain pairs of physical quantities, are a permanent feature of physics, one that future developments in physics will have to respect.

(B) *Descriptive incompleteness.* The quantum theory is descriptively incomplete. The state function describes only ensembles of systems. At best it is an incomplete or partial description of the individual case.

(C) *Real states and locality.* Spatially separated systems have individual "real states." The "real state" of one system is not immediately influenced by what is happening to other systems from which it is spatially separated.

(D) *Real states and observables.* The quantum "observables," however, are not suitable for specifying the "real states" of physical systems. One sign of this is the inherent limitation on the empirical determinability of these quantities marked by the uncertainty formulas, as in (A).

(E) *The new physics: Realist and determinist.* To overcome the descriptive incompleteness in (B), one must look for new physical concepts and build a new physical theory. As in (C), the concepts of the new physics will allow for the description of the "real states" of individual systems (hopefully in a space/time framework). The new theory will not involve probability fundamentally. Rather, probability will come in only at the empirical level due to measurement uncertainties, especially in recovering the empirical constraints now associated with the quantum observables. The quantum theory, including its observables, should emerge from the new physics as some sort of limiting case. (This vision of Einstein's for a new, fundamental physics is *not* a proposal for a hidden variables extension of the quantum theory.)

There are many aspects about Einstein's thinking on the quantum theory, however, that are neither clear nor constant. Among them are his remarks about descriptive incompleteness and ensembles—that is, remarks that signal his own construal of the theory and the particular interpretation of the sate function to which he subscribed. With regard to clarity we must recognize that although Einstein frequently raised these topics, he seldom amplified his remarks, and never specifically enough to constitute any definite and detailed account. With regard to constancy, the situation is even more intriguing. If we attend to the interpretive opinions that Einstein expressed in a variety of different writings and contexts, we find that they do not all point in the same direction. Indeed, the most obvious fact about "Einstein's interpretation of the quantum theory" is that he espouses not one interpretation but three. I suppose this fact is so apparent to readers who have examined Einstein's works that, to my knowledge, no commentator on "Einstein's interpretation of the quantum theory" has felt the need to point it out. Apparent or not, there are three recognizable interpretations to be found in Einstein's writings: an instrumental interpretation, a subjective interpretation, and a hidden variables interpretation. Of the three, the literature has focused only on the hidden variables interpretation. I will, therefore, discuss the other two first.

2. The Instrumental Interpretation

In 1948, Wolfgang Pauli organized a special issue of *Dialectica* devoted to discussions of the interpretive problems of quantum theory. It contains essays by Niels Bohr and Albert Einstein, among others, and a brief introductory essay by Pauli himself. In his introduction Pauli explains Bohr's philosophy of complementarity in (reasonably) clear and sympathetic terms, and he also deals with Einstein's reservations about the incompleteness of the quantum theory — reservations he rejects. In the introduction Pauli offers an account of what he pointedly refers to as the attitude of physicists "actually working in the field of modern quantum theory," which is clearly his own too. Pauli writes:

> In the general case only statistical predictions can be made regarding the results of further observations. The general theoretical statements about a given "state" of a physical system therefore refer to a statistical ensemble of many systems equally prepared. I am inclined to consider this renouncement of the quantum mechanical description on the predictability by laws of the individual observation on a single atomic system in a given state as the fundamental new result of the point of view of complementarity. (Pauli 1948, 309)

The pointed criticism did not miss its target, for in correspondence with his old friend Michele Besso, Einstein mentions his own contribution to *Dialectica* and reacts to Pauli's response.

> I am pleased that you read my little article. Did you notice how illogical Pauli's response was? He denies that this sort of description is incomplete, but in the same breath says that the ψ-function is a statistical description, the description of an ensemble of systems. This is just another form of the assertion: the description of the single (individual) system is incomplete! For almost everyone, momentary success has more power of persuasion than considerations of principle, and fashion makes people deaf — at least for a while. (Letter to Besso, 24 July 1949, Speziali 1972)

Einstein goes on to refer Besso to his "Replies" in the Schilpp volume (Schilpp 1949, 665–92), where he says he has written something else on the same subject so that "at least posterity will know how I thought about it."

If we were to construct a picture of Einstein's ideas from these remarks to Besso, we would have to say that descriptive incompleteness amounts to the assertion that the ψ-function describes an ensemble of systems, not an individual system. This is the recurring theme of (B) above. But what does the ψ-function describe about the ensemble? In the preceding passage, Pauli offers the customary account — namely, it describes the statistics of the results of observations of systems in the ensemble. This is the position that Einstein refers to as "a statistical description" when he points out to Besso that although Pauli says he denies incompleteness, he affirms it in the same breath. It is, in fact, the interpretation of the state function that Einstein himself often used in his own descriptions of the quantum theory, where he would say, for example, that what quantum mechanics provides is "an indirect description . . . from which the probability of the results of any conceivable measurement can be computed" (Einstein 1950, 757); or that state functions "serve only to make statistical statements and predictions of the results of all measurements which we can carry out upon the system." (Einstein 1940, 491)

Here then we have an instrumentalist version of Einstein's statistical interpretation of the quantum theory: the ψ-function describes an ensemble of systems, in the sense that it describes the statistics for results of observations of systems in the ensemble. This version is just a qualitative formulation of the Born rule, and indeed Einstein sometimes refers to this conception as Born's interpretation, or Born's statistical interpretation — for example in his contribution to the Born *Festschrift,* where he sums up with this remark:

> The result of our considerations is this. So far the only acceptable interpretation of the Schrödinger equation is the statistical interpretation due to Born. This allows, however, no real description for the individual system, rather only statistical assertions concerning ensembles of systems. (Einstein 1953a, 39–40)[3]

In this instrumentalist version the statistical assertions are not about possessed or premeasurement values but about the probability for finding measured values. Einstein can be very clear and emphatic about the difference.

> The aim of the theory is to determine the probability of the results of measurement upon a system at a given time. On the other hand, it makes no attempt to give a mathematical representation of what is actually present, or goes on in space and time. On this point the quantum theory of today differs fundamentally from all previous theories of physics, mechanistic as well as field theories. Instead of a model description of actual space-time events, it gives the probability distributions for possible measurements as a function of time. (Einstein 1940, 491)

[3] All translations are by the author, unless otherwise indicated.

3. The Subjective Interpretation

The published "Replies" that Einstein refers Besso to in the July 1949 letter were condensed from a more extensive set of responses that Einstein was preparing. Among these responses was one to Walter Heitler's contribution (Schilpp 1949, 179–98). In his survey of the quantum mechanical "departures from classical thought" Heitler particularly stressed that observation — and indeed the "acknowledgement by a *conscious being*" — is required to collapse the wave packet so as to obtain a definite result of measurement. In his unpublished response Einstein suggests that this interpretation of the collapse is due to Heitler's treatment of quantum mechanics as a complete description of individual systems, a familiar theme. As we have come to expect, Einstein counterposes that treatment with one he prefers — namely,

> that one conceives of the psi-function only as an incomplete description of a real state of affairs, where the incompleteness of the description is forced by the fact that observation of the state is only able to grasp part of the real factual situation. Then one can at least escape the singular conception that observation (conceived as an act of consciousness) influences the real physical state of things; the change in the psi-function through observation then does not correspond essentially to the change in a real matter of fact but rather to the alteration in *our knowledge* of this matter of fact. (Unpublished reply to Heitler, 1948)

An account of the state function in terms of our knowledge of things recurs in several other places as well.

Writing to Ernst Cassirer in 1937 about Cassirer's *Determinism and Indeterminism in Modern Physics* ([1936] 1947), Einstein describes the basic EPR setup in order to explain why he thinks that quantum theory is not a satisfactory physical theory from the point of view of fundamental physics. He draws out the difficulty in treating the state function as a complete description, which has to do with the possibility of assigning different state functions to a subsystem in a coupled pair, depending on the measurement performed on the distant subsystem. Einstein continues:

> Naturally, this entire difficulty disappears if one relates ψ_2 not to an individual system but, in Born's sense, to a certain state-ensemble [Zustands-Ensemble] of material points 2. Then, however, it is clear that ψ_2 does not describe the totality of what "really" pertains to the partial system 2, rather only what we know about it in this particular case. (Letter to E. Cassirer, 16 March 1937)

The same idea recurs in correspondence just a month before Einstein's death, where he writes:

> The ψ-function is *not* to be considered as a complete description of an

> individual state of affairs, rather only as a representation of what we can *know* about a particular state of affairs from an empirical point of view. Then the ψ-function is a representation of an "ensemble," not the complete characterization of individual states of affairs. One has thereby renounced the latter in principle. (Letter to A. Lamouche, 20 March 1955)

Einstein makes similar connections between the state function and knowledge in some of his published reflections on the quantum theory. The background seems to be an ignorance interpretation of probability, which is evident in the very interesting notes taken by James Murphy of a conversation with Einstein in 1932. There Einstein responded to Murphy's suggestion that something like free will obtains in inorganic nature with: "That nonsense is not merely nonsense. It is objectionable nonsense" (Planck 1932, 201). According to Murphy's notes, Einstein went on to say:

> Here then is a question of confounding the subjective with the objective world. The indeterminism which belongs to quantum physics is a subjective indeterminism. It must be related to something, else indeterminism has no meaning, and here it is related to our own ability to follow the course of individual atoms and forecast their activity. (Ibid., 202)

Einstein pursues this theme, in one of the clearest statements of his philosophy of science and his attitude toward the quantum theory, in an address he gave in 1940, published in *Science*. After describing the development of Schrödinger's wave mechanics from the work of de Broglie, Einstein writes:

> But on one point, curiously enough, there was failure: it proved impossible to associate with these Schrödinger waves definite motions of the mass points — and that, after all, had been the original purpose of the whole construction. The difficulty appeared insurmountable, until it was overcome by Born. . . . The de Broglie–Schrödinger wave fields were not to be interpreted as a mathematical description of how an event actually takes place in time and space, though of course they have reference to such an event. Rather they are a mathematical description of what we can actually know about the system. They serve only to make statistical statements and predictions of the results of all measurements which we can carry out upon the system. (Einstein 1940, 491)

Finally, in his "Autobiographical Notes" for the Schilpp volume, Einstein uses features of coupled systems, as in the letter to Cassirer referred to earlier, to argue for the following interpretation: "The ψ-function is no exhaustive description of the real state of the system but an incomplete description; it expresses only what we know on the basis of former measurements concerning the system" (Schilpp 1949, 83).

This line of thought, which connects the state function with incomplete knowledge, yields a subjective version of Einstein's statistical interpretation of the quantum theory. In the subjective version the ψ-function represents our knowledge of some (but never all) empirically determinable features of a system. The ψ-function describes our state of knowledge of an ensemble of systems each of which is known to have a limited number of empirically determinable features in common. Just as the instrumentalist version amounts to a qualitative formulation of the interpretation generally associated with Born, this subjective version is a statistical interpretation of the sort often associated with E. C. Kemble (1937).

4. The Hidden Variables Interpretation

> While we have thus shown that the wave function does not provide a complete description of the physical reality, we left open the question of whether or not such a description exists. We believe, however, that such a theory is possible. (Einstein et al. 1935, 780)

This is the closing paragraph of the EPR paper. The reference to the possibility of a complete theory has been seen as pointing to a hidden variables interpretation of the quantum theory. Although one might take that reference as pointing instead to the new physics envisioned by Einstein (recall (E) of section 1), rather than to hidden variables, there are some reasons internal to the EPR paper for thinking that hidden variables are being suggested. The second part of the EPR paper notes that we can directly measure either position or momentum on one system in a coupled pair and use that to infer the value of position (or momentum) in the distant and unmeasured system without disturbing it, in the course of arguing that the unmeasured system must already possess values of both variables. The argument is complex and makes use of the "criterion of reality" stated in the first part of the paper: "If, without in any way disturbing a system, we can predict with certainty (i.e., with probability equal to unity) the value of a physical quantity, then there exists an element of physical reality corresponding to this physical quantity" (ibid., 777). The (simultaneous) values of position and momentum for the unmeasured system go beyond what the quantum theory itself provides and may thus be considered "hidden" from the point of view of the theory, and as giving a more "complete" description. More generally, one might suggest that the form of a hidden variables interpretation alluded to in the EPR paper is a theory in which each of the quantum observables possesses a definite value at all times.

While such a point of view may well be suggested by the argument of the EPR paper, it is by no means clear that the suggestion is Einstein's. As I have explored elsewhere (Fine 1988, chap. 3), EPR was actually written by Podolsky, and Einstein was dissatisfied with and distressed by the published text, which he thought obscured his own line of thought. In particular, Einstein did not think that incompleteness rested on arguing that a microsystem possesses "hidden" values for observables. Rather the argument that Einstein favored (as in the 1937 letter to Cassirer cited in section 3) had to do with the fact that by performing different measurements on one system in a coupled pair, we could assign different state functions to the unmeasured system. That system, however, must have a "real physical state," and one not affected by the distant measurements. Thus more than one state function can be associated with a single real state. Einstein concluded from this that the descriptive apparatus of the quantum theory was incomplete. This line of argument does not use the criterion of reality, which in the original EPR paper is the basis for assigning "hidden" values. In fact, Einstein never made reference to (or use of) that reality criterion in any of his own published remarks on the quantum theory (ibid., 63, n. 24). Thus the usual basis for ascribing a hidden variables account of the quantum theory to Einstein is not compelling.

Nevertheless there are some places where Einstein's own discussions do call for hidden variables. I have in mind passages like these:

> The individual system (before the measurement) has a definite value of q (or p) for all variables of the system, and more specifically, *that* value which is determined by a measurement of this variable. (As translated in Schilpp 1949, 83)

> The (free) particle really has a definite position and a definite momentum, even if they cannot both be ascertained by measurement in the same individual case. According to this point of view, the ψ-function represents an incomplete description of the real state of affairs. (As translated in Born 1971, 169)

These passages were written in 1948–49, and they occur in the context of discussions of quantum incompleteness. Einstein anticipated these passages a decade earlier in correspondence with Tanya Ehrenfest, where he wrote, "I see myself required to ascribe, at least to a *free* particle, not only a fixed p but also a fixed q" (letter of 12 October 1938). In this citation, as in the first of the two passages quoted above, Einstein hedges the assignment of the "hidden" premeasurement values, restricting them to "free" particles. Elsewhere he expresses even deeper reservations. In an earlier work (Fine 1988, chap. 5) I discussed Einstein's route to incompleteness via Schrödinger's cat and his own pile of gunpowder precursor. This line involves premeasurement values only for observables of macroscopic systems, like the cat or the gunpowder. In his later years Einstein tended to prefer this way of highlighting the incompleteness of the quantum theory, since the premeasurement values it produces are not hidden but manifest (the cat is either alive or dead, the pile of gunpowder explodes or does not). This route does not require the postulation of individual real states, and their separability, in order to demonstrate incompleteness. In his contribution to the 1953 de Broglie *Festschrift* Einstein goes so far as to assert that only in the case of macroscopic systems can we decide for sure whether the quantum theoretic descriptions are actually incomplete: "Can this theory [i.e., the quantum theory] provide a real description for an individual case? This question must be answered, 'No.' For this decision it is essential that one deals with a macro-system" (Einstein 1953b, 37).

Einstein does not display these various reservations in his introductory essay for the Schilpp volume, referring there to values for all the variables (i.e., I take it, observables) without restriction. For the most part, however, even when he does postulate premeasurement values for microsystems he mentions only position and linear momentum. As I have pointed out elsewhere (Fine 1988, 54–55, 92–93), in a clearly speculative context Einstein sometimes also considers the possibility of there being definite decay times.

Given the range of variation in Einstein's restrictions and hedges, one cannot give a capsule formulation of some particular "hidden variables interpretation" to which Einstein subscribed. We can say with assurance only this much. On certain occasions Einstein's remarks point to the introduction of hidden variables according to which, for at least some systems, some observables have premeasurement values in at least some non-eigenstates (of those values). We would be on shaky ground were we to attribute anything more definite to Einstein. To be sure one could propose some special statistical construct as a candidate for the type of hidden variables theory to associate with Einstein's fragmentary texts. A local deterministic hidden variables theory represents one such construct, as does the refinement of this that I refer to as a prism model. There are other candidates as well (for the prisms, see Fine 1988, chap. 4, and Fine 1989; for another possible candidate, see Fine 1973). Each construct attends to certain reflective currents in Einstein's thinking about ensembles, which it extends and embellishes while ignoring others.

5. Refutations

Despite the difficulty in pinning Einstein down on hidden variables, the no-hidden-variables theorems in the foundational literature are frequently taken as refuting Einstein. In view of the three different types of interpretations he embraced, it seems amazing to think of refuting something called "Einstein's interpretation." In fact, the connection of these theorems with Einstein is usually based on the mistaken association of his ideas with deterministic hidden variables, traced out above, via the EPR paper. Elsewhere I have attempted to debunk a popular version of this "refutation" that rests on Bell's theorem and its purported connection to Einstein's ideas about locality (Fine 1988, chap. 4). More recently there have been related "no-go" results that feature the EPR criterion of reality and derive a contradiction from it in simple and elegant ways (see Mermin 1990, 1991). Since it is doubtful that this criterion was ever Einstein's these too miss their mark.

Given the implausibility of refuting Einstein's interpretation, it is interesting to examine what the purported refutations need to do in order to put Einstein in the picture. Their foremost requirement is a definite target to be shown incompatible with the quantum theory as it is usually understood. This requirement makes the instrumentalist and subjective treatments of the state function inappropriate, since these treatments are carefully tailored to accord with the formalism of the theory. Thus in reading Einstein on the quantum theory, one needs not to notice (or at any rate, not to call attention to) Einstein's espousal of these sorts of interpretations. Instead, to "refute" Einstein one must see only his hidden variables route, for that clearly goes beyond the quantum framework insofar as it posits premeasurement values for observables in non-eigenstates of those values. Here, perhaps, would be a toehold for a refutation. To complete the job, however, one also needs a definite construct. To this end it is necessary to ignore the whole range of cautious and alternative opinions that Einstein expressed about premeasurement values, including his mature conclusion that the case for them is compelling only for macroscopic systems. So the refuting tradition settles instead on local hidden variables theories as Einstein's own, in general — thereby putting up a definite target to shoot down.

There is more than careless reading and scholarship involved in the project of using the no-hidden-variables results to discredit Einstein. That project derives from the early struggles over the proper understanding of the quantum theory and the desire on the part of the proponents of the theory to certify its viability in order to attract to it the best scientific minds. From its earliest moments Einstein stood out in dissent from the whole quantum program, which he regarded as a blind alley for physics. In short order Einstein became the most forceful and influential critic of the program. A vigorous offense is often a good defense; therefore it is not surprising to see the growth of a tradition of finding fault with Einstein. Since the quantum program felt the need to show Einstein wrong, it is also not surprising that the purported refutations were received without a great deal of scrutiny concerning the extent to which they accurately reflected Einstein's views. Anyway, physicists are not scholars, and when one needs to shoot something down it is not useful to discover that one's objective has rather the character of mist.

The tradition of targeting Einstein, fostered during the 1930s in defense of the quantum program, continues even today when the quantum theorists need not be so defensive. No doubt this is due in part to the fact that a research practice tends to legitimize itself, to build a community of investigators and thus prolong its life span. In part the recurrent interest in refuting Einstein is also due to his extraordinary scientific fame — fame enough even today to make questioning of any aspect of Einstein's scientific work an immediate source of attention.[4] Thus by recognizing the importance of Einstein as a critic of the quantum theory we get some insight into the peculiar features of the refuting tradition. Focusing on

[4] Note, for example, how Will (1986) advertises his discussion of the evidence for general relativity.

Einstein's role as a critic can also help us understand the interpretive leeway that he reserved for himself with regard to the theory.

6. Einstein as Critic

Einstein used the incompleteness (as he saw it) of the quantum theory to call attention to the essential role of probability and statistics in the theory. He regarded this aspect of quantum mechanics as a major defect, and he looked forward to a more deterministic physics, one where probability would not enter in a fundamental way. By setting that incompleteness in the context of instrumental and subjective interpretations, Einstein pointed to the way that the quantum theory either brackets the question of an objective description of real states (instrumentalism) or simply replaces it by a subjective representation. This was the "risky game . . . with reality" that Einstein found so objectionable (letter to Schrödinger, 22 December 1950). Thus Einstein's instrumental and subjective interpretations of the quantum theory serve to highlight the two features of the theory that he found most difficult to accept, its indeterminism and its irrealism. Einstein believed these to be linked defects. In his repeated contrasts between a complete and an incomplete interpretation, and in his arguments against completeness, Einstein was trying to show that one cannot treat quantum indeterminism as realism of a higher order. To do so would be tantamount to treating the stochastic information contained in the quantum state function as a complete description of the individual system. He argued, however, that quantum indeterminism is simply not compatible with realism, since when one postulates real states of affairs the quantum theoretic description turns out to be incomplete.

To describe a thing as incomplete is to suggest the possibility of something more. That is to say, the very language Einstein chose for his critical discussions of the quantum theory is one that inevitably points to the prospect of some better, more complete theory. As we have seen, the unsatisfactory features of the quantum theory brought out by Einstein's interpretations were precisely the defects he hoped a new physics would overcome. He summarized just this line of thought in his "Replies," as follows:

> There exists, however, a simple psychological reason for the fact that this most nearly obvious interpretation [that the state function "refers to ensembles of systems and not to individual systems"] is being shunned. For if the statistical quantum theory does not pretend to describe the individual system (and its development in time) completely, it appears unavoidable to look elsewhere for a complete description of the individual system; in doing so it would be clear from the very beginning that the elements of such a description are not contained within the conceptual scheme of the statistical quantum theory. (Schilpp 1949, 672)

Thus when Einstein took up the interpretive challenge of the quantum theory it was not only as a critic and dissenter, he also wanted to point the research community in what he took to be a better direction for physics. In short, his interpretations were hortatory as well as descriptive.

It is important to keep this hortatory aspect in mind when we try to understand Einstein's vacillating engagement with hidden variables. In particular, one should note that the hortatory function would be jeopardized if we understood him to hold that what the quantum theory actually treats, albeit statistically, is a determinate domain whose individual features are entirely objective and knowable. Such an account interprets the quantum theory as a deterministic hidden variables theory. To accept it would lead one to look (as de Broglie and Bohm did) for a more satisfactory and detailed treatment of the underlying determinate and objective domain. It would encourage, that is, the active development of hidden variables physics. That path, however, was not the one that Einstein followed in his own research, nor a path that he admired or encouraged in others.

Einstein believed that the task for physics is to search for the "real states" of physical systems, to find new concepts that will refer to them, and to develop a new conceptual framework for their treatment. This framework should provide the basis for a fundamental physical theory that will not involve probability in an irreducible way. Such a theory may involve principled limitations in measuring the nonelementary variables, since it will have to yield quantum mechanics — including the uncertainty formulas — as some sort of limiting case (see ibid., 666–67). According to this conception the complete description is something "after which one must search" (letter to Pauli, 2 May 1948). For the concepts that go into this complete description, the ones that describe the real state of affairs, will have to be different from those of the quantum theory. As Einstein put it to Pauli in the same letter, "Naturally this complete description would not come out of the fundamental concepts used in point-mechanics."

The idea that the theoretical description of real physical states is not to be given in terms of the classical concepts is a persistent feature of Einstein's thought. He expressed such sentiments to George Breit in 1938, when he wrote that the complete description of the individual system "cannot be obtained within the framework of the concepts of classical mechanics" (letter to Breit, 2 August 1938). Einstein later repeated it to Aron Kupperman this way: "I think in general that one cannot arrive at a description of the individual system through a simple completion of the present statistical quantum theory" (letter to Kupperman, 14 November 1953). A year later, after setting out his reservations about the de Broglie pilot wave theory to R. Hosemann, Einstein characterized the situation as follows:

> The present quantum theory is in a certain sense a magnificent self-contained system that, at least in my opinion, cannot be made into an individual-theory by supplementing it, any more, e.g., than Newtonian gravitational theory can be made into general relativity by supplementation. Somehow one must

> start from scratch, hard though that obviously is. (Letter to Hosemann, 9 August 1954)

The search for new physical concepts in order to get a complete description of the real physical states of individual systems seems to represent Einstein's program for how to "complete" the quantum theory. One must build a new and different theory, one that does not treat the classical dynamical variables as fundamental but only yields information about them in some sort of limiting case. Thus one would not expect to be able to describe the real state of affairs for an atomic object simply by filling in the gaps in the quantum description — for example, by specifying coordinates for both position and momentum. This would not be a description of the real state, and the resulting "hidden variables" theory would not be the new physics that Einstein was promoting. I believe this is the sense of Einstein's harsh-sounding remark to Born about Bohm's (and by implication de Broglie's) hidden variables theory, which does fill in the value gaps for the classical variables: "This way seems too cheap to me" (Born 1971, 192). In his correspondence with Bohm, Einstein put it more gently:

> In the last few years several attempts have been made to complete quantum theory as you have also attempted. But it seems to me that we are still quite remote from a satisfactory solution to the problem. I myself have tried to approach this by generalising the law of gravitation. But I must confess that I was not able to find a way to explain the atomistic character of nature. My opinion is that if an objective description through the field as an elementary concept is not possible, then one has to find a possibility to avoid the continuum (together with space and time) altogether. But I have not the slightest idea what kind of elementary concepts could be used in such a theory. (Letter to David Bohm, 28 October 1954).

Completed descriptions in terms of the classical dynamical variables were not on Einstein's agenda. Thus if Einstein's interpretations pointed us in the right direction for future work in physics they would not just be pointing to the task of supplementing the classical descriptions via hidden variables.

What then might Einstein have had in mind in those moments when he clearly invoked hidden variables of some sort? One possibility might be the refinement of the hidden variables program to which I referred at the end of section 4, the prism models. Suppose, as Einstein certainly did, that the quantum observables — including the dynamical variables — fail to pick out objective features that are empirically determinable in all cases. Further, suppose one thought that the limitations on the empirical determinability of conjugate variables brought out by the uncertainty formulas indicate a deeper limitation on the measurability of the individual variables, a limitation of the following kind. When a single variable can be measured, one can do so to any desired degree of accuracy; however, not all systems can be measured for all variables (even taken one by one). Such a conception leads to inherent measurement inefficiencies that could easily be seen as the ground of the statistical descriptions required by the theory.[5] Moreover this framework would certainly give one reason to be dissatisfied with the basic theoretical concepts themselves, precisely as Einstein was, since even if all systems were to possess premeasurement values for all the variables, the values could not all be determined empirically. Note, however, that although this conception does allow one to ascribe simultaneous possessed values to noncommuting observables, it does not force one to do so in all cases. For instead of saying that the value of a variable cannot be determined by measurement, one could say that the object does not possess a value for that variable. Thus on different occasions one might well speak differently about whether all variables do or do not possess values and still have the same general hidden variables framework in mind. This flexibility is built into the prism model approach to hidden variables. I have argued that it provides a better setting for the few detailed remarks that Einstein made about how hidden variables are supposed to work than does the simpler conception of deterministic hidden variables (see Fine 1988, chap. 4; Fine 1990). Here I suggest that the prism approach to hidden variables also offers a framework in which we can see how, at different times, Einstein might have expressed somewhat different commitments on the question of which variables have values. Moreover, if we want to introduce "real physical states" to overcome the limitation on measurability involved in the prisms, we would have to look outside the theory for a new fundamental conceptual framework, which was exactly Einstein's goal.

The prisms certainly capture some of Einstein's reservations about the quantum theory and its observables. Nevertheless, like other attempts to pin a specific hidden variables construct on Einstein, they too embellish his fragmentary texts. If asked whether prisms *really* represent what was in Einstein's mind concerning incompleteness, ensembles, and the inherent limitations on measurement, one could do no better than to take a cue from the master himself and respond: "It seems to me a smile is the best answer" (Einstein 1950, 758).

7. Concluding Remarks

As Einstein saw it, the "flight into statistics" enabled the quantum theory to hang onto the classical dynamical concepts even though they were not capable of yielding an objective and empirically satisfactory description of physical reality. He wrote to Schrödinger: "Your claim that the concepts p, q will have to be given up if they can only claim such 'shaky' meaning seems to me fully justified" (letter of 31 May 1928; see Fine 1988, 18ff.). Einstein used the idiom of "incomplete descriptions" to express these reservations. Alternatively, he would say that the state function refers to an ensemble and not to the individual system. The rhetoric

[5] These inefficiencies make the prism models testable, at least in certain cases (see Fine 1989, 1991).

here indicates at once the stance of a critic and that of a guide, one whose criticism is intended to help physics find a better way. I have argued that if we set Einstein's interpretive writings on the quantum theory in the context of these dual functions (critical and hortatory) we are free to notice that Einstein actually offers three "interpretations" of the quantum theory: an instrumental one, a subjective one, and something in the area of hidden variables. Each of them suits Einstein's critical and hortatory purpose. Each points to the theory's indeterminism and irrealism, and each points beyond. Perhaps for this reason Einstein saw no need to pick and choose among them. At any rate he does not.

Of the three interpretations, the hidden variables one is the most problematic. Einstein was certainly clear that this interpretation, like the others, held no promise for physics (not even heuristically). He was much less clear, however, with regard to just what kind of hidden variables he thought quantum theory might represent. Which variables of which systems have values? (All variables of all systems? Some variables only for free systems? For microsystems? Only for macrosystems?) Despite the latitude in Einstein's various texts, by focusing on the critical and hortatory uses to which he put his interpretations we can at least see that the common construct of a deterministic hidden variables theory, which is usually taken to be Einstein's preferred way, is not in fact a satisfactory portrayal of his ideas.

The customary approach to Einstein's writings sets his role as a critic of the quantum theory and his desire for a different kind of physics in the context of working out an account of his interpretation. That approach places Einstein's interpretation in the foreground of the scholarly picture, and relegates to the background the functional role of the interpretation. This essay has explored what happens if we reverse the order and foreground the functional role. I hope the result has been some gain in our understanding of what Einstein was up to in his interpretive forays, gain enough to comprehend and (perhaps) to tolerate Einstein's considerable interpretive leeway.

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